AFGL-TR-77-0257
AIR FORCE SURVEYS IN GEOPHYSICS, NO. 376

Correction for Ionospheric Refraction for COBRA DANE

RICHARD S. ALLEN
DELIA E. DONATELLI
MARIA C. PICARDI

18 November 1977

SPACE PHYSICS DIVISION PROJECT 4643
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Howard

Chief Scientist

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

9) Air Force surveys in geophysics

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFGL-TR-77-0257	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): 6) CORRECTION FOR IONOSPHERIC REFRACTION FOR COBRA DANE.	5. TYPE OF REPORT & PERIOD COVERED: Scientific. Interim.
	6. PERFORMING ORG. REPORT NUMBER: AFSG No. 376
7. AUTHOR(s): 10) Richard S. Allen, Maria C. Picardi, Delia E. Donatelli	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Geophysics Laboratory (PHP) Hanscom AFB, Massachusetts 01731	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62101F 16) 46430402 17) 04
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Geophysics Laboratory (PHP) Hanscom AFB, Massachusetts 01731	12. REPORT DATE: 11) 18 Nov[redacted]77
	13. NUMBER OF PAGES: 18 12) 19p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 14) AFGL-TR-77-0257, AFGL-AFSG-376	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC APR 26 1978 F

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Regis College Research Center, Regis College, Weston, Massachusetts

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ionosphere
COBRA DANE
Adaptive modeling
Refraction correction
Radar range error
Navigation refraction correction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A hit-to-hit correction for range error arising from ionospheric refraction has been developed for the COBRA DANE radar. First a FORTRAN procedure was developed to compute monthly median refraction corrections over the field of view. These were provided to the radar in the form of equivalent look-up tables. A FORTRAN program was developed for the radar computed index values for each target position (azimuth, elevation, and range) and a correction was determined for each radar hit. This procedure removed about 75 percent of the monthly mean ionospheric effect.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (Cont)

A further reduction was then made by using first an update factor determined by the Air Force Global Weather Central and then a more accurate update derived from a two-frequency calibration made by the radar itself. These procedures are shown to be capable of removing up to 90 percent of the mean ionospheric effect.

Contents

Illustrations

Tables

Correction for Ionospheric Refraction for COBRA DANE

1. INTRODUCTION

Refraction effects within the ionosphere degrade measurements of range and bearing. For the COBRA DANE radar these effects create errors that exceed the required metric accuracy; therefore, a correction must be made for each target. In developing the correction procedure, consideration had to be given to the present and future requirements of the user, the constraints within the particular radar, the forecast capabilities of the Air Force Global Weather Central (AFGWC), the inherent limitations of the ionosphere, and foreseeable techniques that will describe the ionosphere present at the radar. A simple method of correction, based on three-element vectors, provides the equivalent of a look-up table for the entire surveillance volume of the radar. This correction procedure satisfies the present system requirements and has flexibility for expansion as techniques improve or requirements change.

Once a month the vector model is calculated off line by the AFGWC. Used alone by the COBRA DANE processor, it removes about 75 percent of the monthly mean ionospheric effect. Since the requirements for metric accuracy on single missions will become more critical for the enhanced ionosphere at the next solar maximum, provision has been made for refining the correction. This is now done in two ways: first, from worldwide ionospheric observations, the AFGWC determines and supplies a daily update factor to scale the correction hour-by-hour so

(Received for publication 18 November 1977)

as to more accurately represent the current ionosphere; second, using a dual frequency range measurement to certain satellites, the radar determines a scale factor that provides a more precise correction for a shorter time span. The accuracy of this procedure with such scaling factors will depend on the frequency of update. If a scaling factor can be determined in the area of interest as frequently as every 15 min, then perhaps 95 percent of the ionospheric effect can be removed.

2. GENERAL CONSIDERATIONS

The final correction procedure that was delivered and installed in the COBRA DANE radar as software for a real-time hit-to-hit correction for ionospheric refractive effects is an adaptation of the model designed to provide the basic monthly mean correction for the SPADATS mission.[1]

The rationale for the procedure has not been changed. The customer requirements for metric accuracy during the 1980's could not be satisfied by correcting for just the expected monthly median refraction effects, which would have removed only about 75 percent of the day-to-day variability. A procedure was needed to improve upon this basic estimate by some update that could follow local features of the current ionosphere. Yet the constraints within the radar processor on core storage and computation time would not permit consideration of any procedure that was more complicated than a look-up table. Any mapping techniques or line of sight ray tracing methods required real-time evaluation of analytic functions that so reduced throughput within the processor that a correction could not be made on a real-time hit-to-hit basis.

As a specific example, a simple mapping algorithm was developed to represent the expected median correction for the ionospheric range component over the whole field of view. Using 11 Fourier sine terms to represent the longitudinal variation and 11 Tchebyshev polynomials to represent the latitudinal variations, a correction could be calculated that would match the expected value calculated from the original data field with an accuracy near 5 percent. Yet when this minimum sized algorithm was tested on the equivalent CDC radar computer, the computation took so long that a hit-to-hit correction could not be made.

When the only solution to a hit-to-hit correction is a quick access look-up table, then a new problem is created. If a procedure is to be developed that will meet present goals and grow as needs and techniques develop, the cell size in the radar volume must be fairly small. To attain the goal of removing 95 percent of the variability, local features in the ionosphere have to be introduced by some updating

1. Allen, R.S. (1974) An Ionospheric Correction Model for the COBRA DANE Radar, AFCRL Memo LIR/X-2943.

technique. The look-up table procedure then has to be quite fine in azimuth, elevation angle, and height of target—so fine, in fact, that it becomes unreasonable in terms of storage area within the computer.

The proposed solution is an engineering compromise. The goal is the metric accuracy that the user wants for single missions in the ionosphere of the early 1980's. The correction procedure installed in COBRA DANE is a three-vector model that provides the equivalent to a fine-scale look-up table. This vector model is computed for each month from forecasts made by the AFGWC. It is presently in use at the COBRA DANE radar and should be updated by a scaling factor to represent overall ionospheric conditions on the day of operation. As techniques are developed for scaling in space and time to represent the actual local state of the ionosphere during missions, they should be adopted by the radar. The basic monthly mean forecast is the default correction when any of the updates are not available. Most important, the software installed at the radar is small in total storage words and fast in computation time so that a hit-to-hit correction can be made.

3. INTUITIVE DEVELOPMENT OF THE VECTOR MODEL

The problem of devising a method of approximating a very fine scale look-up table is divided into two parts: the estimation of the geometric effect of viewing targets along slant paths, and the estimation of the ionosphere. To meet accuracy requirements, the best correction is made in that portion of the field of view where it is most needed and some degradation is allowed in other areas. Since both the intelligence and the SPADATS missions at the COBRA DANE radar require the highest accuracy for targets embedded in the ionosphere at low elevation angles, the same model can be used for both missions.

The ionospheric and geometric effects cannot be considered separately, simply because the ionosphere has an arbitrary distribution along the slant path to the target. However, the day-to-day variability about the forecast of the monthly mean ionosphere is about 10 to 20 percent for each parameter, much larger than would be expected from the variation along the slant path. With this justification, the ionosphere is defined at the central position of the slant path and geometric effects are calculated as if the ionosphere were spherically stratified.

The elements of a look-up table to provide a correction over the entire radar volume can be ordered by orthogonal unit vectors for azimuth, elevation angle, and target height. In this model the ionosphere is determined near the horizon where the greatest accuracy is desired, and the geometric effects are determined along these vector directions so that the refraction correction, C_{ijk}, can be computed within the radar by simple multiplication:

$$C_{ijk} = C_o (S_i\, Y_j\, E_k)\, U\,,$$

where

(1) C_o is the magnitude of the correction in feet, at the prime reference point, azimuth 319° T, height 1000 km, and elevation 5.3°.

(2) The obliquity factor, S_i, is a 33-element vector for the variation with elevation angle evaluated at the reference azimuth and height (310° T and 1000 km), normalized to 1.0 at 5.3° elevation.

(3) The partition factor, Y_j, is a 33-element vector for the variation with the height of the target evaluated at reference azimuth and elevation angle (319° T and 5.3°), normalized to 1.0 at 1000 km.

(4) The ionospheric factor, E_k, is a 33-element vector for the variation with azimuth evaluated for the vertical ionosphere at the center of each azimuthal sector near the horizon (5.3° elevation, 420 km height). This is normalized to 1.0 at boresight, 319° T, and has been weighted for the variation of S (5.3°) with azimuth.

(5) The update factor, U, represents the current ionosphere, either the scale factor from the AFGWC or a recent local measurement.

From the 101 stored values (C_o + S + Y + E + U), the radar computer can generate the equivalent elements of a 35,937 value look-up table. As a result of the definition of the reference conditions, the correction is most accurate in the precision sector, and for those targets that require the greatest correction. As the target coordinates shift away from the reference point, the vectors depart from their true values, but the magnitude of the correction decreases so that a larger percentage error can still be tolerated. For instance, for a target near 80° elevation, the ionosphere may be 2 hours removed from the reference, but the obliquity element, S, at 80° is about one-third that at 5.3°.

The result is a very small, very rapid computer program for generating hit-to-hit corrections with fine-scale coverage over the entire radar volume and an error that is minimized at the maximum correction. The value in any cell of the equivalent look-up table is expected to be within a few percent of that expected when using the monthly mean prediction. In addition, the correction for refractive effects can be updated for local conditions.

4. COMPUTATION OF VECTOR ELEMENTS BY AFGWC

A Fortran subroutine (subroutine DANE) has been developed which computes the required vector elements to be used at the radar. The subroutine is tailored to COBRA DANE by internal Fortran data cards that specify the 33 ionospheric reference points at the center of each azimuth sector and the geometric values pertinent to the 33 elements of the obliquity and partition factors. It is initialized at the AFGWC by specifying the desired month and the estimated 12-month running mean of the sunspot number and the 2800 MHz solar flux. The subroutine then calls a standard subroutine available at AFGWC, such as the Damon/Hartrampf or Bent procedures, for building the expected electron density profile at the reference points. This standard subroutine calculates and returns the vertical total electron content (TEC in el/cc) up to 1000 km and the height (hmF2 in km) of the peak of the F2 region.

Subroutine DANE then uses hmF2 at boresight, sector 17, to calculate the obliquity factor, SHAH:

$$\mathrm{SHAH\,(EL)} = [2.02 - 0.0053(\mathrm{hmF2} - 290)]\ \frac{(95.-\mathrm{EL})}{739000}$$

for each of the 33 stored values of elevation angle (EL). Also, for boresight, the partition factor, Y, is calculated for each of the stored values of height (HT):

$$\mathrm{Y(HT)} = 1. - \mathrm{B}/\left[\mathrm{B} + \left(\frac{\mathrm{HT}-100.}{\mathrm{hmF2}-100}\right)^{3}\right] .$$

where

$$\mathrm{B} = 1.81 + 0.001\,(\mathrm{hmF2} - 290) .$$

Note that, by definition, Y approaches 1.0 at 1000 km. The reference value, C_o, is then calculated for each hour:

$$C_o = \frac{1.3225\times 10^{-10}}{F_{op}}\ \mathrm{TEC(17)\,SHAH(5.3^\circ)}\ \text{(in feet)} ,$$

where the radar operating frequency, F_{op}, is nominally 1275 MHz. The obliquity factor is then normalized to 1.0 at the reference elevation, 5.3°,

$$\mathrm{S(EL)} = \mathrm{SHAH(E)/SHAH(5.3^\circ)} ,$$

and the TEC at each azimuthal position, (AZ), is normalized to boresight and weighted by the obliquity factor for each azimuth at 5.3° elevation.

$$E(AZ) = \frac{TEC(AZ)SHAH(AZ,\ EL)}{TEC(17)SHAH(AZ,\ 5.3°)} \, ,$$

to provide the 33 elements of E, the azimuthal vector, which is normalized to 1.0 at boresight.

The output of subroutine DANE is a set of 10 punched cards for each integer hour of Universal Time (0-23), as shown in Figure 1.

Horizon Refraction Correction (in feet) — Universal time — Field of View — Source — Radar COBRA DANE — Year — HR — card #

OCT 1977, HOUR 0. CO = 29.14, EL=0-80, AZ=254-U24 GWC/AFGL/CD 7710 00

0.00	0 00	0.00	.00	.04	.13	.26	.40	.54	.65	.73	I--HT	7710	01	
.80	.84	.88	.90	.92	.93	.95	.95	.96	.97	.97	I--HT	7710	02	(1) Variation with height
.98	.98	.98	98	.99	.99	.99	.99	.99	.99	.99	I--HT	7710	03	
1.03	1.02	1.01	1.00	.95	.92	.88	.85	.81	.79	.75	SineL	7710	04	
.72	.69	.66	.63	.60	.58	.55	.53	.51	.49	.47	SineL	7710	05	(S) Variation with elevation
.45	.43	.41	.40	.38	.37	.35	.34	.33	.32	.31	SineL	7710	06	
.96	.94	.93	.93	.91	.91	.90	.90	.91	.91	.92	TANAZ	7710	07	
.93	.93	.95	.96	.98	1.00	1.03	1.04	1.07	1.09	1.12	TANAZ	7710	08	(E) Variation with azimuth
1.14	1.17	1.19	1.22	1.24	1.25	1.28	1.30	1.31	1.35	1.38	TANAZ	7710	09	

Figure 1. Format of Cards Produced by GWC/AFGL Program

The normalizing condition for the elevation angle and for the ionospheric control point was chosen at 5.3° to provide an accurate correction in the region of greatest need and to diffuse the error in the 0 to 15 deg elevation region. The analytic forms of the obliquity and partition factors were derived from an AFGL study of electron density profiles obtained from the Millstone Hill incoherent scatter radar. These functions are a best-fit to the expected daytime values of a high mid-latitude ionosphere.

5. COMPUTATION OF REFRACTION CORRECTION BY COBRA DANE

A précis of the subroutine used by the COBRA DANE radar to correct for the ionospheric component in the range measurement is as follows:

(1) Each hour the central processor stores 101 words (C_0 + S + Y + E + U) to provide vectors for the refraction correction, supplied on cards for each month by AFGWC.

(2) The hourly value of the update factor supplied via Autodin by the AFGWC is resident in storage. When a pulse-pair measurement has been made with one of the calibration satellites, it is automatically entered into the subroutine and used in place of the AFGWC value. When the time since a calibration exceeds 3 hours, or if the user determines it is erroneous, the update reverts back to the AFGWC value.

(3) For each hit or batch of hits, the subroutine is entered with the readily accessible coordinates of target position: the sine of the elevation angle, the range, and the tangent of the angle off boresight. For the refraction correction these are redefined as follows:

- An index for the elements of the vector S is defined by dividing sine E to provide 33 equal increments of sine E from 0° to 80°:

  $$s = \mathrm{sinE}/0.03077 + 1.$$

  In addition to being a fast computation, this also provides greater definition near the horizon where it is most needed.

- As proposed by Katz and Boak,[2] it is convenient to order the variation with height by the transformation

  $$I = K((r/R)^2 + 2(r/R)\mathrm{sineE}).$$

  The constant K is defined when I is 33 at 1000 km and R is the radius of the earth. This transformation, nearly linear in height interval, avoids transcendental functions. The average spacing, about 31 km, is about half of the characteristic scale size near the peak of the F region, so again the cell size is fine scale.

- Another easily computed index proposed by Katz and Boak[2] is

  $$e = \tan\Delta AZ/(1. + 0.2\tan^2\Delta AZ),$$

  where tanΔAZ is the tangent of the angle off boresight. This provides a fine spacing of about 4° of azimuth in the precision

---

2. Katz, A.H., and Boak, III, T.I.S. (1977) Interface Control Document for the COBRA DANE Ionospheric Range Correction Model, Raytheon ER77-4089.

sector, increasing to about 5° at the edge of the coverage area.

- The correct elements of the vectors S, Y, and E are calculated by linear interpolation between the stored values. The range correction is calculated by simple multiplication:

$$C = C_0 S(s) Y(I) E(e) ,$$

and is returned by the subroutine.

6. UPDATE FOR CURRENT IONOSPHERIC CONDITIONS

At present there are two update procedures, both of which are a scaling of all of the corrections in the field of view by the single update factor U. The basic default update is that supplied by AFGWC from their world observations. This update factor is a set of hourly factors, provided on a daily basis. It is defined as

$$J(HR) = ETEC/PTEC ,$$

where, for each hour of the predicted period, ETEC is the new estimation and PTEC is the baseline prediction supplied by the card to the radar, both for the vertical electron content at the reference coordinates of the precision sector, 63.2°N., 150.6°E. The 24 values of the update factors are supplied to the COBRA DANE radar via Autodin in decimal notation and are entered directly into the computer by the operator.

A short-time-span update is derived by the radar from pulse-pair measurements of the range to certain satellites. This can be made any time the radar can see any one of four calibration satellites, each with several passes per day, in the sector 299° to 337°T in azimuth and 0° to 42° in elevation. A procedure for doing this has been worked out, tested, and installed in the software at the radar by the contractor.[2] In-house studies at AFGL[3] have shown that this update provides a very significant reduction in the range residuals over short time intervals, but that the factor should revert back to the current AFGWC update when the pulse-pair update is older than 3 hours. In practice, the radar tries to renew the pulse-pair update within the limits of 1/2 to 3 hours.

3. Donatelli, D.E. (1977) Reduction of the Uncertainty of Radar Range Correction, AFGL-TR-77-0125.

7. EFFECTIVENESS OF UPDATING TECHNIQUES

A study of the temporal variability of the total electron content (TEC) of the ionosphere, as measured from a mid-latitude station,[3] has yielded results that can be applied directly to the COBRA DANE radar to estimate the effectiveness of the updating technique using pulse-pair measurements. Range correction is directly proportional to TEC, and for an L-band radar the proportionality constant for range correction, in feet, is 0.7 × TEC in units of 10^{16} el/m^2.

The average day-to-day variability of TEC is 20 to 25 percent of its monthly median in daytime and 30 to 35 percent at night. This percentage error is nearly independent of seasonal and solar-cycle variations. The absolute error is 2 to 3 times greater in daytime than at nighttime.

An updating technique combining the use of pulse-pair measurements with a model prediction of median range correction can reduce the residual error significantly, particularly in daytime when the error is greatest. Evaluation of an updating technique using 9 years of data from Hamilton, Massachusetts (in a simulation of actual use by a 1300 MHz radar on a target at 1000 km altitude, 5 deg elevation angle), has shown that an updated prediction of the median range correction can reduce the residual error by 60 percent, even after 1 hour. In the daytime, when the largest correction is needed, the residual error can be reduced 30 percent or better, even after 3 hours. Attempts to use the updating factor for a period longer than 3 hours results in an error that is of the same order as the error that results by simply using the predicted median. Near sunrise and sunset and during severe magnetic disturbances, all of which are periods of rapid change in TEC, the same degree of error reduction can be maintained by reducing the interval for determining new updating factors to about 15 to 30 minutes.

The results of this study are summarized in Table 1 for the solar maximum condition, $\bar{S} = 155$, $\bar{R}_z = 110$, and the solar minimum conditions, $\bar{S} = 71$, $\bar{R}_z = 10$, where S is the 12-month running mean solar flux at 2800 MHz, and $\bar{R}_z$ is the 12-month running mean sunspot number. The values, in feet, of the parameters for range correction and their residual errors are listed at the local times of the daily mean maxima and minima for the periods representing the seasonal maxima and minima.

Table 1. Residual Range Error

	Winter		Vernal Equinox		Summer		Autumnal Equinox	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
	Solar Maximum ($\overline{R}_z = 110$; $\overline{S} = 155$)							
ΔR	75.0	12.5	95.0	17.5	55.0	17.5	90.0	15.0
δR_m	13.5	4.0	16.0	5.5	9.0	5.0	16.0	5.0
δR_{3h}	9.0	3.5	10.0	3.5	6.0	3.5	9.0	4.0
δR_{1h}	5.0	2.3	5.5	2.3	3.7	2.5	3.7	1.8
δR_{30m}	3.5	1.2	3.5	1.2	2.5	1.5	3.0	1.5
	Solar Minimum ($\overline{R}_z = 10$; $\overline{S} = 71$)							
ΔR	22.5	3.5	22.5	3.5	20.0	4.5	25.0	4.5
δR_m	4.0	1.5	5.5	1.5	3.5	1.0	3.5	1.5
δR_{3h}	4.0	1.5	5.5	1.5	3.5	1.0	4.5	1.5
δR_{1h}	2.5	0.8	2.5	0.5	1.5	0.8	2.5	0.8
δR_{30m}	2.0	0.4	1.5	0.3	1.0	0.5	1.5	0.5

ΔR -the ionospheric component of range measurement in feet for a 1300 MHz radar with target at 5° elevation and 1000 km altitude.

δR_m -the residual error in range correction using a median prediction, caused by the day-to-day variability of the ionosphere.

δR_{3h} -the residual error in range correction using a scaled median prediction 3 hours after updating.

δR_{1h} -the residual error in range correction using a scaled median prediction 1 hour after updating.

δR_{30m} -the residual error in range correction using a scaled median prediction 30 minutes after updating.

To estimate the range correction for other values of $\overline{S}$, it is possible to assume a linear relationship between $\overline{S}$ and TEC and interpolate or extrapolate for the desired value.[3]

These results show that the updating technique based on the pulse-pair measurements can successfully reduce the errors caused by the day-to-day variability of the ionosphere for up to 3 hours after the initial calibration.

8. COMPARISON OF AFGWC AND CONTRACTOR PREDICTIONS

Before 30 September 1977, the refraction corrections for COBRA DANE were derived from an independent model developed by the contractor for use during initial tests. Using a set of prediction cards kindly supplied by the contractor, a comparison to the AFGWC predictions was made for the month of September 1977. The two programs both depended on the standard ITS-78 coefficients for determining ionospheric parameters. The essential difference in these two programs was their use of separate techniques for determining the height of the F_2 region, and slight differences in the shape of their electron-density profiles.

A Plot of C_0 (Figure 2) representing the monthly median for September 1977 was made with AFGL's model (sunspot number equal to 20) and compared to Raytheon's model (SSN=20). A variation of about 5 feet was found to exist between the two lines of data, with AFGL data being displaced above Raytheon data, indicating some systematic difference. Also, some non-systematic difference was indicated, as Raytheon data was higher than AFGL data, from 1900 hours to 2000 hours (UT).

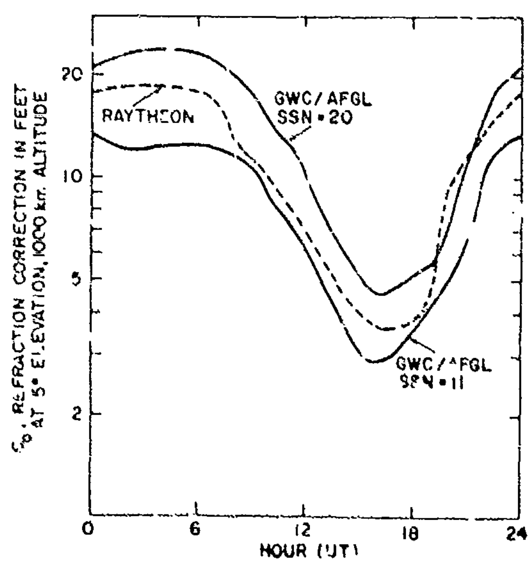

Figure 2. Comparison of Monthly Median Correction as Calculated by Two Models

In an attempt to compensate for the systematic difference found using SSN=20, the sunspot number of AFGL was set at 11. Upon comparison of SSN=11 with the original Raytheon data, it was found that this plot of GWC/AFGL was displaced below the Raytheon line throughout the day. Visual interpretation revealed variation in excess of the previous 5-foot variation, especially at the beginning of the day.

Plots of the azimuth variation (Figure 3) were done for five specific time periods (02, 04, 06, 14, and 22 UT). Data from the two models compared most favorably during the daytime (hours 02, 04, and 06 UT). These points, covering 33 azimuth sectors, showed remarkable similarity between the two models. The lines tended to separate slightly (mostly at 14 UT) at either end of these graphs. In general, Raytheon was displaced above AFGL (especially at the beginning of each line), with the exception of 22 UT wherein Raytheon remained below the AFGL line throughout the plot.

A comparison of the height vector (Figure 4) was done for the following four time periods: 02, 06, 14, and 22 UT, and twin plots of height versus 33 values of height were made. In general, the Raytheon line was displaced above the GWC line, with the exception of the first 11 readings (of height) for the 14 UT plot. The least variation occurred on the 14 UT plot. The most variation occurred on the two extreme time periods of 02 UT and 22 UT.

The prediction for the maximum correction near the horizon (Figure 3) and the variations with azimuth (Figure 3) were very close. This resulted probably because both measurements depended primarily on the value of FOF_2, which was nearly identical in each model. The prediction for the variation in height (Figure 4) was quiet different. This difference was probably due to the fact that height of the F_2 region and the profile shape were determined independently in these two models.

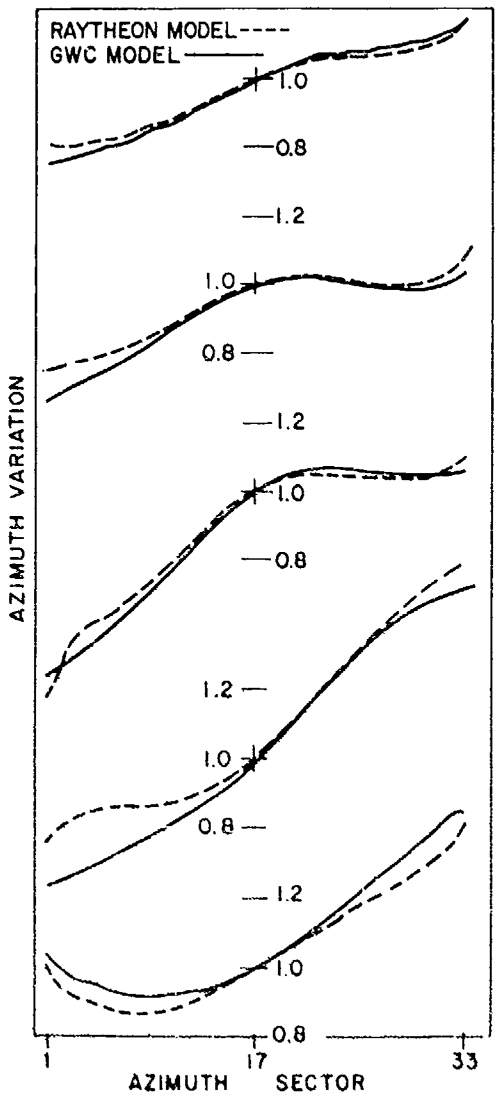

Figure 3. Comparison of Normalized Azimuthal Variation for Raytheon and AFGL Models

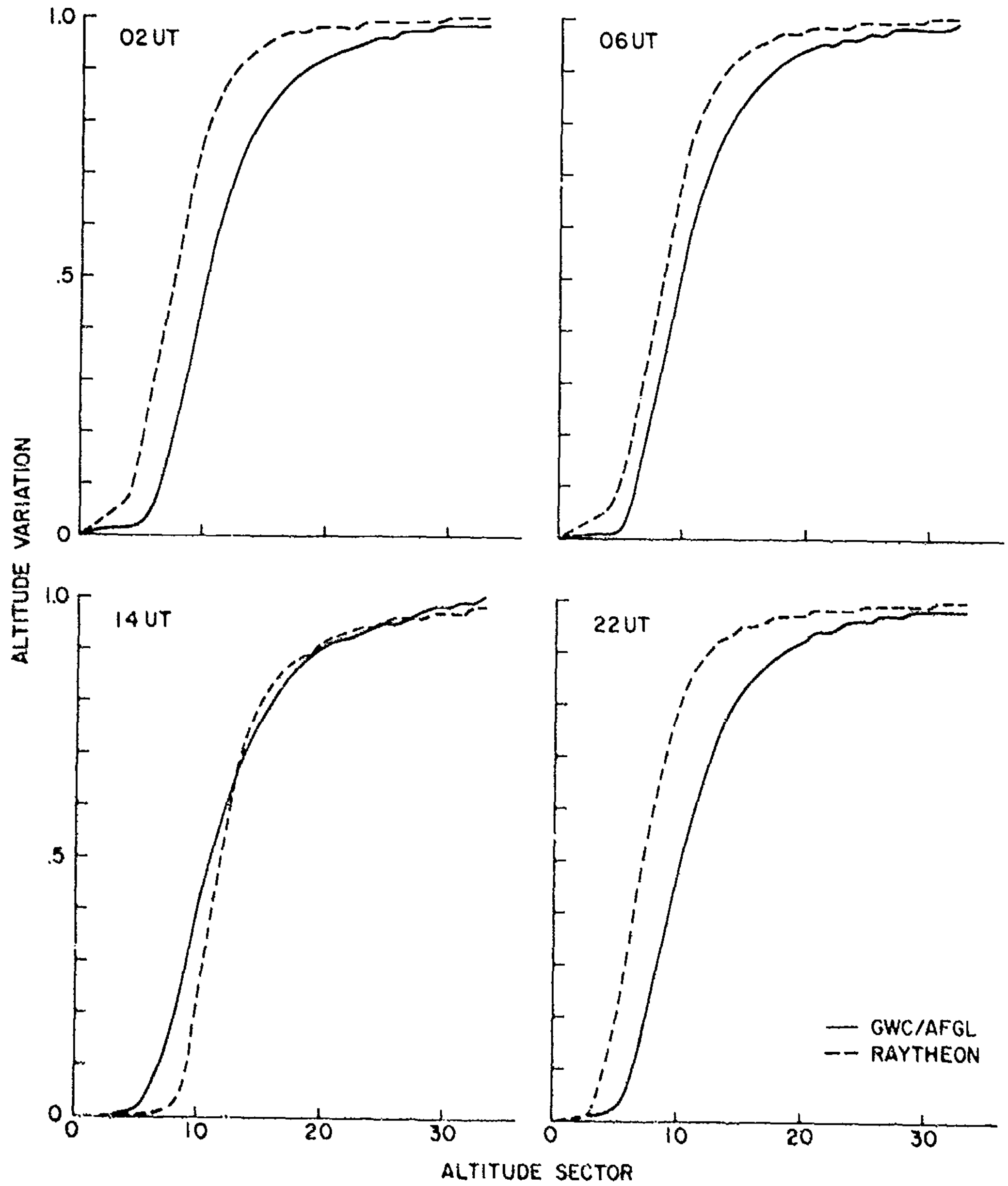

Figure 4. Comparison of Normalized Height Variation for Raytheon and AFGL Models